Increasing Winter Strawberry Production in North-Central Florida Using Passive Ventilated Greenhouses and High Plant Densities

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Abstract

Winter production of strawberry (*Fragaria x ananassa* Duch.) under protected structures can give several advantages to producers over field production. The objective of this research was to determine how increasing plant densities (10.8, 11.7, 12.7, 14, 16.9, 18.3, 20, and 22 plants per m^2) of 'Sweet Charlie' strawberry grown in a passive ventilated greenhouse might improve yield without adversely affecting fruit quality. Plant densities were derived with four between-row spacings (65, 60, 55, and 50 cm center-to-center) and two within-row spacings (17.5 cm and 35 cm plant-to-plant). Strawberry plants were grown in a 'Hanging Bed-Pack' trough system (Polygal Industries, Ramat Hashofet, Israel) that were suspended 1.8 m above the ground level and filled with 6.5 cm^2 sieved pinebark. Marketable yield per m^2 increased linearly with an increase in plant density throughout the season. Early yield per plant was not affected by plant density, however, total yield per plant decreased as plant density increased. Regardless of treatment, the average berry size for early and total yield was 20 g and more than 90 percent of the yield was marketable. A cost threshold was developed by comparing the value of higher early yields when prices are highest, to increased cost of plug transplants at high plant densities. A plant density of 16.9 plants per m^2 led to break-even yields while higher plant densities from 18.3 to 22 plants per m^2 led to increased profits. Thus, high plant populations were required to maximize profits from strawberries grown in passive ventilated greenhouses.

INTRODUCTION

The loss of methyl bromide in the year 2005 (U.S. EPA. 2002), strict regulations on water use at transplanting and for frost protection, rapid urbanization, increasing labor cost, and potential low productivity during winter (Nov to Feb) due to cold weather are some of the major concerns for the Florida annual strawberry industry. Presently, almost 100 percent of the strawberry production in Florida is done in open fields on raised beds fumigated with methyl bromide and covered with plastic mulch. The majority of production occurs during January and February, when the market price for strawberries is high.

Because the Florida strawberry industry is characterized as competitive, maximizing yield is critical for maximizing profits in the higher-priced off-season winter market. Protected cultivation can offer a viable alternative to Florida strawberry growers to meet this challenge. Strawberries are grown under protective structures in the Netherlands, Belgium, Italy, Spain, U.K., (Lieten, 2001), Australia, Israel, and many other countries. Maximum space-utilization by increasing the plant density without compromising yield per plant and fruit quality is critical for the profitability of a protected strawberry operation.

Studies conducted with protected strawberry cultivation during the past few decades have examined a wide range of plant densities from 5.3 plants per m^2 (Sarooshi and Cresswell, 1994) to 32 plants per m^2 (Durner, 1999), with yields ranging from 1.6 kg per m^2 (Sarooshi and Cresswell, 1994) to 7.8 kg per m^2 (Durner, 1999). Various growing techniques such as NFT (nutrient film technique) (El-Behairy et al., 2001; Sarooshi and Cresswell, 1994), soilless culture (Takeda, 2000), and aquaculture with fish-effluent (Takeda, 1993) have been evaluated. Due to the risk of spreading diseases such as red stele (*Phytophthora fragariae*) and crown rot (*Phytophthora cactorum*) through NFT systems (Dijkstra et al., 1993), culture in soilless substrates as opposed to NFT has been considered as a safer option for protected strawberry cultivation. Soilless substrates such as peat, perlite, cocofiber, pinebark, and rockwool have been evaluated for their suitability in protected strawberry culture. In a greenhouse study done during Fall 2000 in north-central Florida (Paranjpe et al., 2000), the yield and quality of 'Sweet Charlie' strawberries grown in bags filled with perlite, peat + perlite, or pinebark were not significantly different. Ozeker et al., 1999, reported no significant differences in yield with pumice + perlite, perlite + peat, pumice, or perlite. Thus, the decision of choosing one substrate over another may largely depend on cost and availability of these substrates since previous studies have not shown dramatic differences in terms of the yields obtained from these substrates. Pinebark is readily available in Florida, is relatively inexpensive, and gives yields that are comparable to peat and perlite. Therefore, pinebark was selected for the present study.

A variety of containers (growing systems) such as polyethylene bags placed in vertical (Ozeker et al., 1999) or horizontal orientation (Lieten, 1997; Dijkstra, et al., 1993), styrofoam pots stacked vertically (Carpenter, 1999), plastic pots placed horizontally (Maher, 1989), PVC gutter sections lined with corrugated plastic sheets (Itzhak Secker, personal communication), PVC pipes with drilled holes arranged on 'A-frames' (El-Behairy et al., 2001) and arranged vertically (Durner, 1999) have also been tested for protected strawberry cultivation. In two studies where vertically oriented growing systems were used (Takeda, 2000; Durner, 1999), the reduced availability of light in the lower sections of the growing system due to shading was a major limitation for plant growth and fruit yield. The intensity of solar radiation reaching the plant canopy at the bottom end of a vertical tower of seven styrofoam pots was only 10% of that reaching the top, thus creating sub-optimal light conditions for normal plant growth in the middle and bottom section of the tower, which resulted in a delayed growth response and lower fruit yield (Takeda, 2000). Durner, 1999, observed that yield per plant increased by 40 g with every 30 cm increase in height of the growing system. Thus, due to the problems associated with uneven distribution of light in a vertically oriented system, it was concluded that a horizontally oriented growing system may be better suited for protected strawberry production.

In the United States, soilless strawberry production under protective structures has been researched but is yet to be adopted on a commercial scale. In Florida, about 0.4 ha are under protected strawberry cultivation (NFREC, 2001). The objective of the present research was to establish a model for off-season protected cultivation of strawberries in north-central Florida by evaluating the effect of different plant densities on the yield and quality of 'Sweet Charlie' strawberry grown in a passive-ventilated greenhouse. A cost threshold was also developed for comparing the increased cost of plug transplants at high plant densities to higher income generated from increased early yields.

MATERIALS AND METHODS

Plug Production and Conditioning

Plug transplants of 'Sweet Charlie' strawberry were grown in a glasshouse at the University of Florida (Gainesville, FL) from 7 June to 15 September, 2001. Propagation trays (51-cell-pack, 5 cm cone x 7 cm deep) (Tray masters of Florida, Sydney, FL) were used for plug production. The plug mix consisted of 1:1 (v/v) of coarse perlite and coarse vermiculite (Airlite Processing Co., Vero Beach, FL). Plug transplants were grown in the glasshouse for 110 days. Since cold conditioning can induce early flowering in strawberry (Sonsteby and Nes, 1998) and enhances winter production of greenhouse-grown strawberries (Durner, 1999), the plugs were transferred to a walk-in cold chamber on 16 September for a two-week conditioning treatment (9-hour photoperiod, 25°C day / 15°C night temperature) to induce early flowering

Growing the Plants in the Greenhouse

After two weeks of conditioning, strawberry plugs were transplanted in a passive-ventilated, high-roof, double-polyethylene greenhouse (Top Greenhouses Ltd., Rosh Ha'ayin, Israel) located at the Horticulture Research Unit, University of Florida (Gainesville, FL). The height of the greenhouse was 9 m, with 1-m high roof-vents and 3.6-m high side-walls covered with a 0.6 mm insect-screen, and retractable polyethylene side-wall curtains. The greenhouse was equipped with heaters (Sundair Inc., Baltic, SD) that were operated to maintain a minimum temperature of 3 to 5°C on days when outside temperature was sub-zero. Heaters were operated for eight days during the entire season. Strawberry plugs were transplanted on Oct. 12, 2001 into a 'Hanging Bed-Pack' trough system (Polygal Industries, Ramat Hashofet, Israel). The growing system consisted of PVC troughs having 10-cm bottom width, 12-cm wall height, 60-mm diameter planting holes, and 17.5 cm distance between planting holes. The troughs were suspended 1.8 m above ground level and filled with locally available 6.5 cm^2 sieved pinebark (Elixson Wood Products Inc., Starke, FL). The troughs were spaced 65, 60, 55, and 50 cm apart (center-to-center), resulting in four between-row spacings. Plugs were either transplanted in every hole (17.5 cm within-row spacing), or every alternate hole (35 cm within-row spacing). The combinations of four between-row spacings (BRS) and two within-row spacings (WRS) resulted in eight plant densities (10.8, 11.7, 12.7, 14, 16.9, 18.3, 20, and 22 plants per m^2). Treatments were replicated four times in a split-block design. Plants were irrigated with drip tape (Chapin Watermatics Inc., Watertown, NY) having 5-cm emitter spacing and 9.45 ml discharge per minute per emitter. Each plant received about 140 ml nutrient solution per day. The nutrient solution was dispensed from two separate stock tanks by two injectors (Dosatron Inc., U.S.A.) assembled in series. The nutrient concentrations in the nutrient solution were adapted from a hydroponic tomato formula (Hochmuth, 1990) and consisted of 80 ppm N, 50 ppm P, 85 ppm K, 95-100 ppm Ca, 40 ppm Mg, 56 ppm S, 2.8 ppm Fe, 0.6 ppm B, 0.4 ppm Mn, 0.2 ppm Zn, 0.1 ppm Cu and 0.03 ppm Mo. The pH of the final solution was maintained between 6.0 and 6.5 and the E.C. ranged between 1.4 and 1.6 $mS \cdot cm^{-1}$.

Pest and Disease Control

The major insect pests were cotton aphids (*Aphis gossypii*), green peach aphids (*Myzus persicae*), two-spotted spider mites (*Tetranichus urticae*), and western flower thrips (*Frankliniella occidentalis*). The aphids were controlled by releasing biological agents such as *Coleomegilla maculata* larvae, nymphs of *Geocoris punctipes* (Entomos Inc, Gainesville, FL), and *Aphidius colemani* parasitic wasps (IPM Laboratories, Locke, NY). *Neosiulus californicus* predatory mites (Benemite Inc., CA) were used to control two-spotted spider mites and *Orius insidiosus* adults (Entomos Inc, Gainesville, FL) were used to control thrips. AQ-10 (*Ampelomyces quisqualis*) biofungicide [Ecogen Inc. Langhorne, PA] was used for controlling powdery mildew (*Sphaerotheca macularis).*

Pollination, Harvesting, and Data Analysis

One bumblebee hive (Koppert Biological Systems Inc., MI) containing approximately 50 bumblebees (*Bombus impatiens)* was placed in the greenhouse 15 days after transplanting and remained there until the end of the season.

Fruits were harvested at 80 percent red color development at 4 to 5 day intervals. Fruits weighing more than 10 g were considered as marketable whereas fruits which weighed less than 10 g or which were deformed or diseased were considered culls. Yield data were subjected to analysis of variance and the Duncan's Multiple Range test was used to compare treatment means at P=0.05 using SAS software (SAS, 1999).

RESULTS AND DISCUSSION

Early Yield

Fruits were harvested from Nov 28, 2001 to Mar 22, 2002. The first 13 harvests from Nov 28 to Jan 28 were considered early yield. The first harvest was 42 days after transplanting which was similar to strawberry experiments done during previous seasons in the same greenhouse. For the early yield per m^2 (Nov 28 – Jan 28) there was an interaction between BRS and WRS (P = 0.015). Early yield per m^2 increased linearly from 2.2 kg per m^2 to 4.3 kg per m^2 as plant density increased from 10.8 to 22 plants per m^2 (Table 1). On the other hand, the marketable yield per plant was similar at all plant densities. There was no interaction between BRS and WRS for marketable yield per plant and it was similar for all BRS and WRS (Table 2). Thus, in the present study, the linear increase in early yield per m^2 at higher plant densities was due to the greater number of plants per unit area, and not due to differences in the yield per plant.

The average fruit weight increased from 20 g to 20.4 g per fruit with increasing BRS in a quadratic response (data not shown). The WRS affected average fruit weight wherein fruits weighed 21 g with a 35 cm WRS as compared to 19.7 g with a 17.5 cm WRS (data not shown). The marketable fruit weight increased linearly from 92 % to 93 % as BRS decreased from 65 cm to 50 cm (data not shown).

Under field conditions, low night temperatures can delay yield. In this study, the adverse effect of low night temperatures on plant growth was minimized since the experiment was conducted in a passive ventilated polyethylene greenhouse with supplemental heating provided when necessary. The PVC gutters used in the present study were arranged parallel to each other in a horizontal plane with a north-south orientation to ensure that plants on both sides of the PVC gutters were uniformly exposed to a maximum amount of solar radiation. The need for walkways was reduced by elevating the growing system to1.8 m where fruit harvest was made more efficient.

Total Yield

There was an interaction between BRS and WRS (P < 0.0001) for the total (Nov 28 – Mar 22) marketable yield per m^2. Total marketable yield per m^2 increased linearly from 4.7 kg per m^2 to 8.9 kg per m^2 as plant density increased from 10.8 to 22 plants per m^2 (Table 1). There was no interaction between BRS and WRS for total marketable yield per plant (Table 2). However, in contrast to the observations for early yield, WRS had a significant effect (P<0.0001) on the total marketable yield per plant wherein a higher yield of 426 g per plant was obtained at 35 cm WRS, compared to 412 g per plant at 17.5 cm WRS. The BRS and WRS did not influence the average fruit weight or percentage of marketable fruit weight (data not shown).

During the season, *Aphidius colemani* effectively controlled aphids, and *N. californicus* predatory mites were effective in controlling two-spotted spider mites especially during the warmer months of February and March. From January onwards, there was a severe incidence of powdery mildew (*Sphaerotheca macularis*) which infected strawberry foliage, flowers, and fruits in all stages of development, and there was limited success in controlling this disease with AQ-10 bio-fungicide.

Cost Threshold

As plant density increased from 10.8 to 22 plants per m^2, the cost of plug transplants increased from $19,400 to $39,600 per ha. The cost of other inputs such as the growing system, drip-tape, soilless media, packaging material, cooling, freight, and the labor cost for setting up the growing system, transplanting, and harvesting also increased with increasing plant density. However, during the early season, the increment in income (due to higher production per unit area) for plant densities greater than 16.9 plants per m^2 was greater than the increment in the cost of production (Figure 1). This resulted in positive returns to management at plant densities greater than 16.9 plants per m^2. This effect was due to an increase in early yield per unit area and a decrease in cost of production per plant at higher plant densities. Early returns to management increased linearly as plant density increased from 10.8 plants to 22 plants per m^2. The returns to management for the total season were positive at all plant densities (data not shown) and increased linearly with increasing plant density.

CONCLUSION

In Florida, the average total yield for field-grown strawberries during the 2000-01 season was 3 kg per m^2 (Florida Agriculture Facts Directory, 2002). Since plant density in protected strawberry cultivation can be five times greater than the plant density in the field, and warmer air temperatures can be maintained inside the protective structures during winter, early yield from greenhouse-grown strawberries can surpass the total yield of field-grown strawberries.

During the early season (Nov to Jan), plant densities greater than 16.9 plants per m^2 gave positive returns to management. As plant density increased from 10.8 plants to 22 plants per m^2, yield and returns to management per unit area for the early and total season increased linearly. Further research is necessary to test whether these linear trends will continue for plant densities greater than 22 plants per m^2. The use of locally available and relatively inexpensive soil-less substrate like pinebark (\$8.50/m^3) eliminates the need for methyl bromide and offers a cost-effective alternative to more expensive and commonly used soilless substrates like perlite (\$40.70/m^3) and peat (\$69.25/m^3). In conclusion, protected strawberry cultivation at high plant densities can enhance early production, which, at higher market prices, can translate into higher income.

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Tables

Table 1. Effect of between-row spacing (BRS) and within-row spacing (WRS) on early and total marketable fruit yield (kg per m^2) of 'Sweet Charlie' strawberry grown in a passive ventilated greenhouse in Gainesville, FL during Fall 2001.

WRS (cm)	BRS (cm)	PLANT DENSITY (plants per m^2)	EARLY (kg per m^2)	TOTAL (kg per m^2)
17.5	50	22	4.3	8.9
	55	20	4.2	8.3
	60	18.3	3.7	7.7
	65	16.9	3.3	7.0
35	50	14	2.7	5.9
	55	12.7	2.5	5.4
	60	11.7	2.2	5.0
	65	10.8	2.2	4.7
			LSD = 0.222	LSD = 0.129

Table 2. Effect of between-row spacing (BRS) and within-row spacing (WRS) on early and total marketable fruit yield (g per plant) of 'Sweet Charlie' strawberry grown in a passive ventilated greenhouse in Gainesville, FL during Fall 2001.

	EARLY (g per plant)	TOTAL (g per plant)
BRS (cm)		
50	195	414
55	202	420
60	197	420
65	199	421
Significance	NS	NS
WRS (cm)		
17.5	201	412
35	196	426
Significance	NS	**
BRS x WRS	NS	NS

NS , ** : F test non-significant at P>0.05, and significant at P<0.01 respectively.

Figures

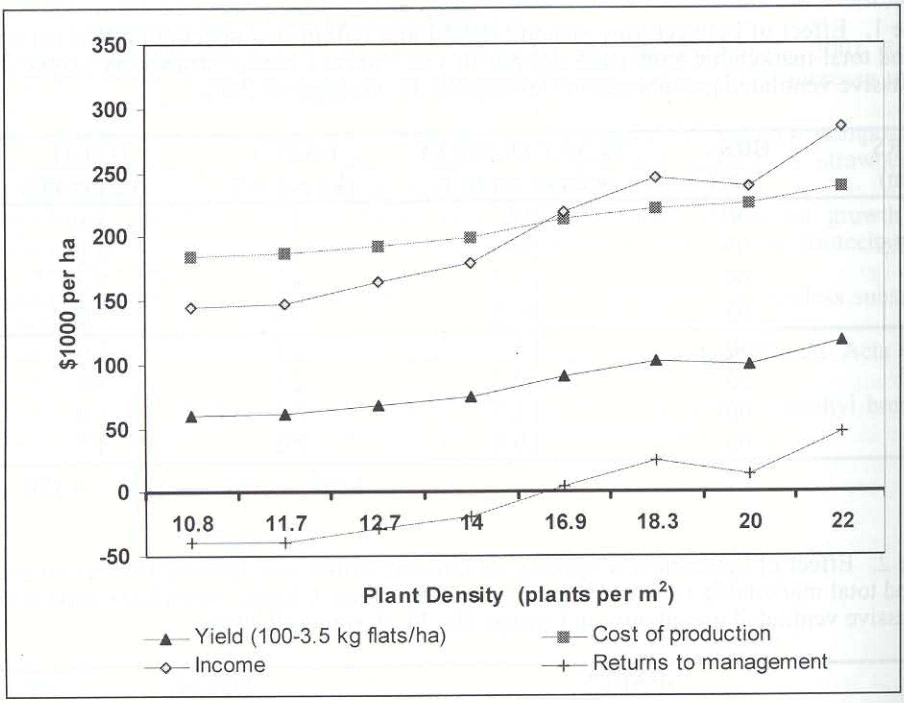

Fig. 1. Early (Oct - Jan) yield, cost of production, income, and returns to management for different plant densities of 'Sweet Charlie' strawberry grown in a passive ventilated greenhouse in Gainesville, Florida during Fall 2001.

Formulae used:
Cost of production = {(Fixed Cost) + (Variable Cost)}
Income = (No. of flats) x (Wholesale market price per flat after 15% commission)
Returns to management = (Income) – (Cost of Production)

Fixed cost includes the following:
Cost of greenhouse structure, construction, heating and ventilation, electricals, vehicles, warehouses, utilities, spray equipment, etc.

Variable cost includes the following:
Cost of plugs, growing system, drip tape, pinebark, fertilizer, packing material, cooling, freight, labor cost for setting-up and cleaning growing system, filling media, transplanting, harvesting, pest control, etc.

Market Prices per 3.5 kg flat (2001-2002 : Miami terminal) Source:USDA - AMS

Month-Year	:	Nov-01	Dec-01	Jan-02	Feb-02	Mar-02
Price	:	$20.4	$26.1	$21.8	$13.8	$13.0